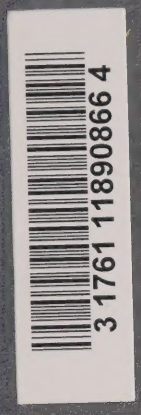

COMPONENT COST OF SOLAR ENERGY SYSTEMS

Ministry of Energy
Ontario

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ABSTRACT

The Solar Demonstration Program is a key element of the Ontario Ministry of Energy Renewable Energy Program. Under the demonstration program a number of residential and commercial/institutional projects have been designed and constructed and are becoming operational.

The cost information from a variety of projects based on actual tender prices is presented and will assist in estimating costs for future projects. When combined with predicted performance data, the capital cost information will also provide the base data for calculation of the cost effectiveness of solar heating in Ontario. Recent cost data from the United States Commercial Solar Demonstration Program Cycle II are also presented for comparison and future trends in costs are discussed, based on work by the MITRE Corporation in the U.S.

Problems that have been encountered in the tendering of solar projects are outlined with suggestions on how to avoid these in future projects. The Ministry expects, in future, to be able to report actual performance data on current projects resulting from monitoring program of the National Research Council of Canada or from the Ministry's own performance evaluation program.

INTRODUCTION

The Ontario Ministry of Energy is responsible for co-ordinating a program to promote the effective use of renewable energy resources. In order to introduce and promote a new technology, such as solar energy, into an established energy infrastructure, an orderly plan from research and development to demonstration and assessment leading to commercialization and market acceptance, is required. The outline for such a plan is shown in Figure 1 (1)*.

Although a major portion of the solar program is concerned with technical development and assessment, a number of social-political-legal aspects must also be addressed. Some of the major items in this category include:

- development of standards and warranties for solar energy equipment to provide consumer protection
- development of methods to ensure access to sunlight since even the best equipment will not operate if sunlight is not available

*Numbers in () denote references listed at the end of paper.

- development of acceptable techniques to interface solar energy systems with existing utilities

- development of curriculum and courses for students as well as training and certification programs for the solar installation trades

- development of a data base and a program to disseminate available information.

By simultaneously pursuing both the technical and institutional-legal aspects of solar energy development, when proven economical systems are available, the necessary climate and infrastructure will be in place to accommodate such systems.

SOLAR DEMONSTRATION PROGRAM

One of the major subactivities of the Ontario Ministry of Energy Renewable Energy Program is the solar demonstration program. This program has two major short term objectives, namely:

i) to provide factual information on the design, construction and performance of solar energy systems in Ontario so that an assessment of various systems can be made and the most cost-effective concepts identified, and

ii) to encourage technical development by allowing the private sector to gain experience and knowledge in the design, manufacturing, and installation of solar energy systems at no financial risk.

As in the United States, such a demonstration program is a key step to commercialization of solar technology in Canada and Ontario.

Since solar energy systems, particularly in Canada, have only been built in the last few years, studies (2, 3, 4) attempting to determine the cost effectiveness of solar energy have been based on theoretical estimates of the two most significant parameters;

i) the thermal performance, and

ii) the initial capital cost.

During 1978 and 1979 the thermal performance of a number of the demonstration projects will be evaluated and information published which will reduce the uncertainty in the first of these parameters. In the interim, however, the initial cost of these projects is available and is being used to refine the calculations associated with determining the economic viability of solar energy systems.

The urgency of providing information on the initial cost of solar energy systems is obvious when tendered prices are compared to estimates

available in the literature. Higher initial capital cost, of course, will delay the decision to install a solar energy system and consequently reduce the contribution (in the short term) that solar energy can make to meeting Ontario's, or even Canada's, energy demand.

CAPITAL COST OF DEMONSTRATION PROJECTS

The solar energy demonstration program has included both small systems for providing space heating and/or domestic water heating for individual residential applications, and large systems for space heating and/or water heating in commercial and institutional buildings. For the purpose of this paper, residential and commercial/institutional solar energy systems are discussed separately.

Large Solar Energy Systems

One of the earliest demonstration projects was the Aylmer Senior Citizens Apartment Building. This building is an 1850 square meters (20,000 square feet), two storey apartment with 30 individual living units built to high standards of thermal performance. The solar energy system is designed to provide a substantial portion of the space heating and domestic hot water heating energy. The system consists of 220 square meters (2375 square feet) of flat plate collector and 900,000 litres (200,000 gallons) of water storage. The cost of the solar energy system is shown in Table No. 1.

Another large solar space heating demonstration project is the Applewood Public School in St. Catharines. The school is a two storey structure with a floor area of 1850 square meters (20,000 square feet) incorporating special energy conservation techniques. The heating system is a solar assisted heat pump. The project consists of 230 square meters (2480 square feet) of flat plate collector and 45,000 litres (10,000 gallons) of water storage. Solar energy is also used to heat the domestic hot water directly when sufficient energy is available. The system has been calculated to save 362 gigajoules (343 million B.T.U.'s) and satisfy about 78 percent of the combined heating and domestic hot water load. The cost of the solar energy system is shown in Table No. 2.

A third demonstration project is a retrofit installation to preheat service hot water at West Humber Collegiate. The school uses approximately 5450 litres per day (1200 gpd) of hot water. The solar energy system is expected to provide approximately 50 percent of the energy to heat the water through 40 Celsius degrees (72 Farenheit degrees). The system has 84 square meters (900 square feet) of flat plate collector and 6800 litres (1500 gallons) of water storage. Since this was a retrofit installation, additional structural steel had to be added to the existing flat roof to support the collectors. The initial capital cost for the solar energy system is shown in Table No. 3.

A summary of the unit costs for the three large systems, expressed in terms of unit collector area is shown in Table No. 4.

As is evident from Table No. 4, the cost of installing the solar collectors is not the major cost of a large solar energy system. In all three demonstration projects, the cost of the mechanical work, which although innovative in design, involves only standard mechanical components, exceeds the cost of the collectors. Theoretical studies have not used this relationship between collector cost and mechanical cost, and consequently, generally underestimate the cost of solar energy systems.

As a first approximation, the installed cost of collectors must be considered as a "variable cost" since this cost is directly proportional to the collector area of the system. The mechanical costs, as defined in Table No. 4, do not vary directly as the collector area. These costs will vary in a step function fashion as major sizing changes are incorporated into the design. For the larger demonstration projects, the mechanical costs are of the same order of magnitude as the installed collector costs.

The balance of the cost that must be added to the collector and mechanical costs to obtain the total system cost, tends to be dependent on the actual system and application. For example, the Aylmer project has a large annual storage system which adds $464 per square meter of collector area ($42.95 per square foot) to the system cost. The Applewood Public School is not heated directly by solar energy but uses solar energy in conjunction with a heat pump. The heat pump in this installation added $70 per square meter of collector area ($6.45 per square foot). Similarly, West Humber Collegiate Institute was a retrofit installation requiring $10,000 of structural steel, adding $119 per square meter of collector area ($11.11 per square foot) to the cost of the system.

It should be noted that the previous discussion has referred to the cost of solar energy systems expressed as a function of the collector area. This has been done in order to provide a comparison of three different projects and to provide the reader with an insight into the relative magnitude of collector costs compared with other costs associated with large systems. It is important to realize, however, that the installed collector cost is the only true variable cost, being directly proportional to the system size. For example, the system at West Humber Collegiate used commercially available mechanical components which only come in discrete sizes. Thus a change in the collector area of $\pm$ 10% would not have affected the total mechanical cost of this project. When the optimum solar energy system is being sought, this fact must be foremost in the designer's mind.

Small Solar Energy Systems

Through the solar energy demonstration program, a number of small solar energy systems, applicable to individual residential dwelling units, have also been tendered.

Hot Water Preheat Systems

Of interest to homeowners would be the tenders received for the supply and retrofit installation of package solar domestic hot water pre-heaters. Such package systems are sold complete with two or three collector panels, storage tank, controls, heat exchanger, and piping.

The specifications used to-date require that the systems provide a minimum of 50 per cent of the energy requirements to heat the average hot water consumption of an average single family home, estimated at 225 litres per day (60 U.S. gpd).

Four of the package systems purchased were retrofitted on existing single family homes. Tenders have also been received for the supply and installation of eight package systems for a rowhouse development presently in design. The cost of both new and retrofit systems are indicated in Table No. 5.

Space Heating for Single Family Units

A solar space heating demonstration in a rowhouse development is presently in design as part of the demonstration program. Each of the rowhouse units will have an individual solar heating system using between eighteen and twenty collector panels of the air heating type. The supply only of the collector panels has been pretendered for this project. The tendered price for the selected panel was $270.00 per panel or approximately $150 per square meter ($14.00 per square foot). Tenders have not yet been called for the installation of the panels, or the balance of the solar equipment.

COMPARISON WITH OTHER DEMONSTRATION PROGRAMS

The federal governments in both Canada and the United States have solar demonstration programs. The Canadian government, through the National Research Council of Canada, has demonstrated solar energy in fourteen single family houses as well as several multiple family dwellings. A comparison of the capital costs for the Federal and Provincial demonstration projects has not been completed to-date, but is urgently needed.

The American government has been very active in a solar demonstration program for a number of years. At the U.S. Department of Energy's conference entitled "Solar Update", the costs of solar energy systems was reported (5). The figures obtained at this conference are reproduced in Table No. 6. As with the Canadian government program, a detailed comparison with the U.S. costs has not been completed, but the necessity of performing this task is appreciated.

FUTURE COSTS OF SOLAR ENERGY SYSTEMS

As with the introduction of any new technology, the cost for the first systems is high. It has been found in the past, however, that a reduced cost per unit is achieved as the accumulated production volume

increased. "This learning or experience factor has been found to apply to both labour intensive and non-labour intensive processes. The experience factor, which takes on classical form typical of technological industries in high growth rate competitive markets, is described as the complement of the cost reduction achieved with each doubling of accumulated production volume (6)."

Although it is unrealistic to expect cost reductions such as those associated with computer technology, a study by the Mitre Corporation (7) stated that cost decreases are expected in collectors as well as system installation costs. This statement is based on the cost of solar energy systems being expressed in constant 1978 dollars.

The "experience curve" which the Mitre Corporation has derived is an 80 percent experience curve. Thus the installed cost of solar collectors and the installation cost of the balance of the mechanical equipment is reduced by 20 percent (in constant dollars) for each doubling of accumulated production volume.

Based on a recent solar collector market survey prepared by Middleton Associates (8), the probable accumulated production of solar collectors for the Canadian market in the next five years is indicated in Table No. 7.

As can be calculated from this table, the accumulated solar collector production volume doubles over four times in the period 1978 to 1982. If an 80 percent experience curve applies to the production and installation of solar collectors then the cost reduction in 1982 would be approximately 65 percent expressed in 1978 dollars. Even such an apparently drastic cost reduction must be put in perspective. If inflation in material and labour costs averaged approximately 10 percent over the same period, the installed cost of the solar collectors would remain the same when expressed in current dollars.

As is evident from the above discussion, there is considerable uncertainty as to the future price of solar collectors and solar energy systems. Recently the Ontario Ministry of Energy let a contract to a team of consultants to investigate the effect that market volume might have on the cost of solar energy systems. Because of the complexity of the subject, a report on this activity will not be available until the next SESCI Conference in 1979.

PROBLEMS EXPERIENCED IN TENDERING SOLAR COLLECTORS AND SOLAR SYSTEMS IN THE DEMONSTRATION PROGRAM

Since solar energy is a new and developing technology, established procedures for tendering and purchasing solar collectors do not exist.

For the three large solar demonstration projects referred to earlier, the solar collectors were tendered on a supply and installation basis.

This procedure was followed since it was felt that for the early projects a team consisting of a manufacturer and a contractor was required to ensure the success of the installation. A number of problems arose from this procedure due to the fact that manufacturers were unfamiliar with contractors and vice versa. Consequently, both groups had difficulty submitting tenders.

In addition, for the large demonstration projects, solar collector tenders were called at the same time as the main building tender call. Until a collector manufacturer was selected, a number of architectural details could not be completed. This resulted in several general contractors expressing concern that they were preparing bids without knowing how the selected solar collector panel would affect the architectural portion of their work.

In an attempt to rectify this problem the solar collector panels have been pre-tendered for the most recent demonstration projects. The tenders have, in addition, been based on a "supply only" contract, separating the manufacturers from the contractors and allowing for a particular product to be detailed as part of the architectural drawings. Although most solar collector manufacturers favour a supply only contract, pre-tendering, by its nature, requires the manufacturers to submit a price for equipment which will not be required on the project for up to a year. Consequently, most manufacturers find it difficult to submit a fixed price for equipment when they are uncertain what their costs will be in the future.

A further problem can occur when solar collector tenders are evaluated, independent of what procedure is followed. Since there are no standards for solar collectors, tenders require the submission of documents verifying the performance and durability of the equipment. Early tenders received for the demonstration projects provided very limited documented information on the performance and durability of the collectors. The bids on one of the very early projects were, in fact, all rejected, because it was felt that there was insufficient information to fairly evaluate the tenders.

It should be noted that the level of documentation is improving with each tender call as manufacturers become familiar with the specification requirements and consequently perform the necessary tests to obtain the documentation. As CSA Standards for solar collectors are developed, and equipment is tested against a standard, the need for documentation to be provided with the tender submission will be reduced.

SUMMARY

This paper has presented the actual costs of solar energy systems which have been tendered as part of the Ontario Ministry of Energy's solar demonstration program. Comments have also been made regarding the future costs of solar energy systems and the problems associated with tendering solar energy equipment.

The most important finding to date, resulting from the Ontario solar demonstration program, is that the installed cost of solar collectors for large projects is less than one half the cost of the solar energy system. In the three large demonstration projects being discussed, the installed cost of the solar collectors was of the same order of magnitude as the mechanical costs.

The supply and installation cost of package solar domestic hot water pre-heating systems, and the supply cost for air heating solar collectors tendered to date have been higher than estimates used in early feasibility studies.

In the process of calling tenders for the solar demonstration projects, a number of problems have been identified. These problems, however, are being resolved as experience is gained in tendering solar equipment. When CSA Standards are introduced for solar collectors, the difficulty in tendering and evaluating solar energy equipment should be dramatically reduced.

In the future, additional solar energy demonstrations will be constructed and commissioned and performance information from existing projects will be obtained. As actual performance information is obtained from the demonstration projects, detailed cost effectiveness calculations will be undertaken. Ultimately, a sufficient data base, encompassing both thermal performance and capital costs, will be available to allow designers to make rational decisions based on documented facts.

REFERENCES

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3. Berkowitz, M.K., "Implementing a Solar Technology in Canada: the Costs, Benefits, and Role of Government", University of Toronto Institute for Policy Analysis, May, 1977.

4. Middleton Associates, "Canada's Renewable Energy Resources, An Assessment of Potential", prepared for Department of Energy, Mines and Resources, April, 1976.

5. U.S. Department of Energy, "The Department of Energy Solar Update", proceedings of conference held in Chicago, July, 1978.

6. The Mitre Corporation, "System Description and Engineering Costs for Solar-Related Technologies" Volume I: Summary, Draft Copy, 1978.

7. The Mitre Corporation, "Systems Descriptions and Engineering Costs for Solar-Related Technologies," Volume II, Report No. MTR-7485. Prepared for United States Energy Research and Development Administration, Division of Solar Energy, June, 1977.

8. Middleton Associates, "The Market for Solar Collectors to 1982", Report prepared for the Ontario Ministry of Industry & Tourism, March, 1978.

FIGURE NO. 1

RENEWABLE ENERGY SUBACTIVITY SOLAR PROGRAM OUTLINE

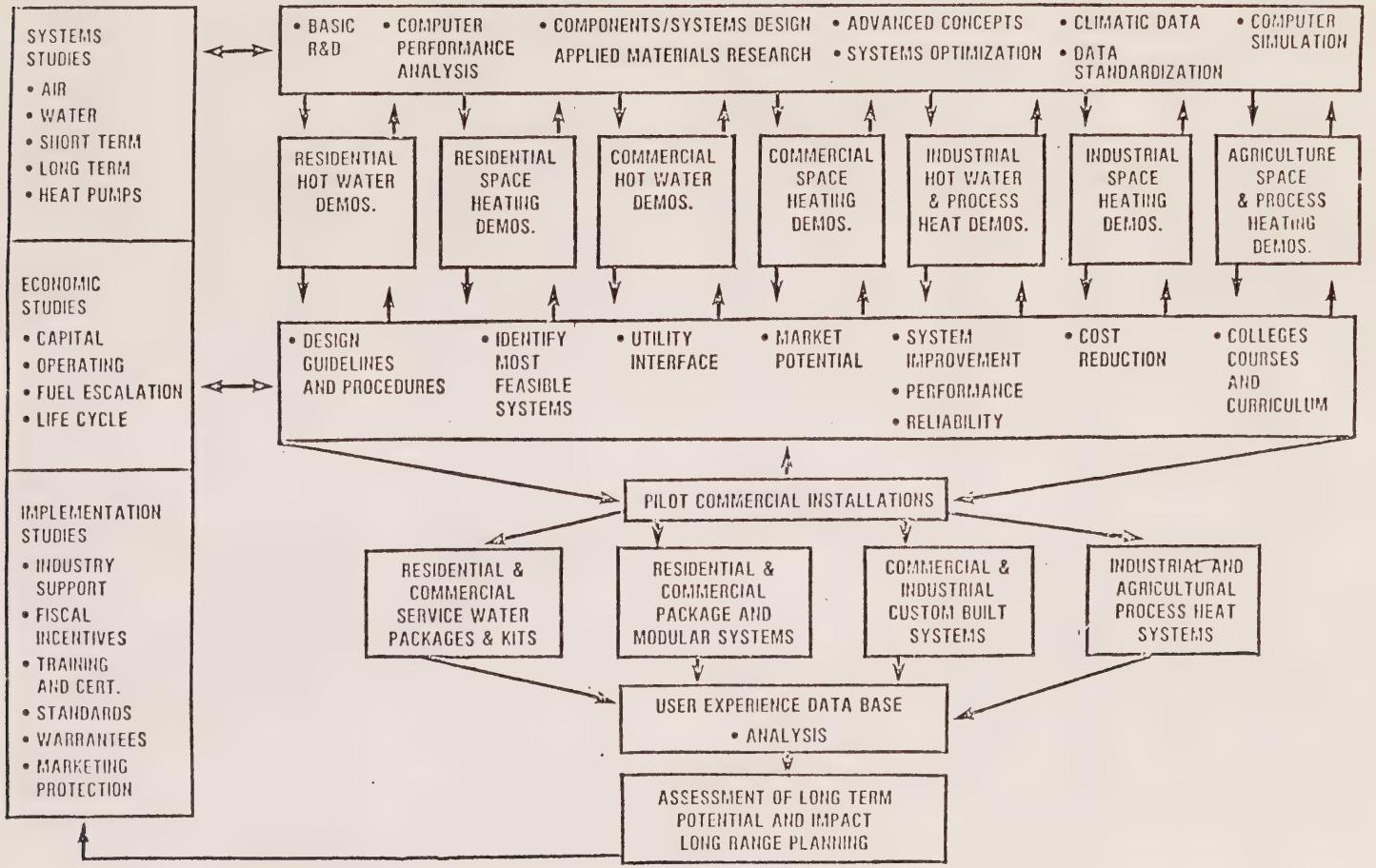

TABLE NO. 1

INITIAL CAPITAL COST

AYLMER SENIOR CITIZENS BUILDING

ITEM	INITIAL COST ($)	UNIT COST $ PER UNIT AREA OF COLLECTOR ($/M^2)	($/FT^2)
COLLECTORS - INSTALLED	$ 61,000	277	25.68
MECHANICAL*	62,000	282	26.11
SUB-TOTAL	$123,000	559	51.79
STORAGE	102,000	464	42.95
TOTAL	$225,000	1023	93.74

*MECHANICAL INCLUDES PUMPS, HEAT EXCHANGERS, SOLAR PIPING, CONTROLS AND SOLAR DOMESTIC HOT WATER HEATING SYSTEM.

TABLE NO. 2

INITIAL CAPITAL COST

APPLEWOOD PUBLIC SCHOOL

ITEM	INITIAL COST ($)	UNIT COST $ PER UNIT AREA OF COLLECTOR ($/M^2)	($/FT^2)
COLLECTORS - INSTALLED	$ 57,000	248	22.98
MECHANICAL*	45,000	196	18.14
CONTROLS	22,000	96	8.87
STORAGE	10,000	43	4.03
SUB-TOTAL	$134,000	583	54.02
HEAT PUMP	16,000	70	6.45
TOTAL	$150,000	653	60.47

*MECHANICAL INCLUDES PUMPS, HEAT EXCHANGER, SOLAR PIPING, EXPANSION TANKS, AND SOLAR DOMESTIC HOT WATER HEATING SYSTEM.

TABLE NO. 3

INITIAL CAPITAL COST

WEST HUMBER COLLEGIATE

ITEM	INITIAL COST ($)	UNIT COST $ PER UNIT AREA OF COLLECTOR ($/M^2)	($/FT^2)
COLLECTORS - INSTALLED	$24,000	286	26.67
MECHANICAL*	26,000	310	28.89
SUB-TOTAL	$50,000	576	55.56
STRUCTURAL	10,000	119	11.11
TOTAL	$60,000	695	66.67

*MECHANICAL INCLUDES PUMPS, HEAT EXCHANGERS, PIPING CONTROLS AND STORAGE TANK.

TABLE NO. 4

SUMMARY

UNIT COSTS

PROJECT	COLLECTOR COST ($/M^2)	COLLECTOR COST ($/FT^2)	MECHANICAL COST ($/M^2)	MECHANICAL COST ($/FT^2)	TOTAL COST ($/M^2)	TOTAL COST ($/FT^2)
AYLMER [1]	277	25.68	282	26.11	1023	93.74
APPLEWOOD [2]	248	22.98	335	31.04	653	60.47
WEST HUMBER C.I. [3]	286	26.67	310	28.89	695	66.67

1. MECHANICAL COST DOES NOT INCLUDE STORAGE.
2. MECHANICAL COST INCLUDES MECHANICAL WORK, CONTROLS, AND SHORT TERM STORAGE BUT DOES NOT INCLUDE THE HEAT PUMP.
3. MECHANICAL COST DOES NOT INCLUDE THE ADDITIONAL STRUCTURAL STEEL.

TABLE NO. 5

INITIAL CAPITAL COST

SUPPLY AND INSTALLATION OF

PACKAGE SOLAR DOMESTIC HOT WATER SYSTEMS

RETROFIT APPLICATIONS

HOUSE 1	$2868.00
HOUSE 2	$2657.00
HOUSE 3	$3046.00
HOUSE 4	$3069.00
AVERAGE	$2910.00

NEW INSTALLATION

UNIT PRICE FOR 8 SYSTEMS	$2740.00

TABLE NO. 6

COST DATA FROM U.S. COMMERCIAL SOLAR DEMONSTRATION PROGRAM ($ 1977 U.S./SQ. FT.)

SYSTEM COST CATEGORY	ARATEX INDUSTRIAL LAUNDRY WATER PREHEAT FRESNO CALIFORNIA	SCATTERGOOD SCHOOL SPACE HEAT AIR SYSTEM	MOSELEY OFFICE BUILDING SOLAR HEAT PUMP
COLLECTORS	11.50	14.60	12.10
SUPPORTING STRUCTURE	2.70	6.90	2.90
PIPING & HEAT EXCH.	8.60	0.20	3.70
DUCTWORK	----	3.20	----
INSULATION	1.60	----	1.90
HEATING/COOLING MECH. EQUIPMENT	----	1.50	4.60
STORAGE	2.30	2.40	3.60
CONTROLS	1.10	1.20	2.50
ELECTRICAL POWER	0.20	0.30	1.50
GENERAL CONSTRUCTION	1.00	0.10	1.70
TOTAL SYSTEM	$29.00/FT^2	$30.40/FT^2	$33.50/FT^2
SYSTEM SUMMARY	GROSS COLLECTOR - 7392 FT^2. TYPE - SINGLE, BLACK PAINT. MOUNTING - FRAME ON FLAT ROOF. STORAGE - 12,500 GAL WATER.	GROSS COLLECTOR - 2730 FT^2. TYPE - DOUBLE GLAZED, BLACK COATING. MOUNTING - ON SOUTH WALL. STORAGE - 1250 FT^3 PEBBLES.	GROSS COLLECTOR - 400 FT^2. TYPE - SINGLE GLAZED, BLACK PAINT. MOUNTING - FRAME ON FLAT ROOF. STORAGE - 2000 GAL WATER

TABLE NO. 7

CANADIAN SOLAR COLLECTOR MARKET

YEAR	ANNUAL SALES (M^2)	ANNUAL SALES (FT^2)	ACCUMULATED SALES (M^2)	ACCUMULATED SALES (FT^2)
1978	16,000	172,500	16,000	172,500
1979	24,000	258,000	40,000	430,500
1980	35,200	379,000	75,200	809,500
1981	58,550	630,000	133,750	1,439,000
1982	90,400	973,000	224,150	2,412,500